Evaluation of Evaporative Cooling Techniques for Energy Efficiency in Buildings

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Abstract

There has been much reliance on energy-consuming technology in cooling, heating and ventilation system to achieve thermal comfort in buildings. Increasing consumption of energy has led to environmental pollution resulting in global warming and ozone layer depletion. Hence to reduce the emission of greenhouse gases, caused by fossil fuels to power the cooling requirement of the buildings has stimulated the interest towards adoption of passive cooling techniques for buildings. Evaporative cooling is a passive cooling technique in which outdoor air is cooled by evaporating water before it is introduced in the building. In this paper, an attempt has been made to evaluate basically three important building integrated passive cooling techniques especially Passive Downdraught Evaporative Cooling (PDEC) and Roof Surface Evaporative Cooling (RSEC) techniques and their significance in climatic control and conserving energy in buildings.

Keywords

Evaporative Cooling; Energy Efficiency; Buildings

Introduction

There has been a grave energy crisis in developing countries especially during summer season primarily due to cooling load requirements of building. The mechanical means of providing thermal comfort are unsuitable because of not only their initial and recurring costs but also non-availability of artificial sources of energy on a regular basis. The building sector represents about 33% of energy consumption in India, with commercial and residential sector accounting for 8% and 25% respectively (ECBC, 2011). Increased living standards in the developed world using non-climatically responsive architectural standards have made air conditioning quite common. Importantly, this has increased energy consumption in the building sector.

Ancient architecture has used various passive techniques to restrict the flow of heat to and from a building. But recently the emphasis on these passive cooling techniques has been neglected due to the availability of electrical supply to run the cooling systems. Actually there are more than 240 million air conditioning units installed worldwide according to the International Institute of Refrigeration (IIR). IIR's study shows that the refrigeration and air conditioning sectors consume about 15% of all electricity consumed worldwide (IIR, 2002). In Europe alone, it is estimated that air conditioning increases the total energy consumption of commercial buildings on average to about 40 kWh/m²/year (Burton, 2001). Increasing consumption of energy has led to environmental pollution resulting in global warming and ozone layer depletion and subsequently having climate change. Hence in this paper three passive cooling techniques namely Passive Downdraught Evaporative Cooling (PDEC) and Roof Surface Evaporative Cooling (RSEC) techniques and direct evaporative cooling (desert coolers) and their significance in climatic control and their role in energy conservation in buildings have been studied.

Environmental Problems Associated with Air Conditioning

There are different problems associated with the use of air conditioning. According to Alternative Flourocarbons Environmental Acceptability Study, apart from the serious increase in the peak electricity load due to the absolute energy consumption of buildings and poor indoor air quality, other important environmental impacts are associated with:

- Emissions from refrigerants used in air conditioning which adversely impact ozone levels and global climate. Refrigeration and air conditioning related emissions represent almost 64% of all Chlorofluorocarbons (CFC) and Hydro Chlorofluorocarbons (HCFC) produced (AFEAS, 2001). The Montreal Protocol has banned the use of HCFC's in developed countries by 2030 and by 2040 in developing countries. It is expected that

around 2025 the production of HCFC's will be banned in Europe, and by 2010 the use of HCFC's will be banned for maintenance and servicing of air conditioners.

- The energy consumption in the cooling systems contributes to CO_2 emissions.

Energy Use in Buildings and Sustainable Architecture

Buildings, a major source of the pollution that causes poor urban air quality, and the pollutants that cause climate change which account for 49 percent of sulfur dioxide emissions, 25 percent of nitrous oxide emissions, and 10 percent of particulate emissions, all of which damage urban air quality. Buildings produce 35 percent of our carbon dioxide emissions, the chief pollutant blamed for climate change (Sustainable, 2013). In India, building consumes one-third of all the energy and two-thirds of all electricity. It is evident that the total energy consumption of buildings for cooling purposes varies as a function of the quality of design and climatic conditions.

Architectural sustainability is linked to the much quoted Brundtland commission report definition through an emphasis on limits to the carrying capacity of the planet, and UK's Building Services Research and Information Association (BSRIA) definition of sustainable construction as 'the creation and management of healthy buildings based upon resource efficient and ecological principle' (Edwards and Hyett, 2001). In principle, sustainable buildings are related to the notion of climate-responsive design, which places emphasis upon natural energy sources with aim to achieve building comfort through the interaction with the dynamic conditions of the building environment (Hyde, 2000). Sustainable architecture aims at creating environment friendly and energy efficient buildings. It is noticed that the total energy consumption of buildings for cooling purposes varies as a function of the quality of design and climatic conditions. In hot climates, commercial buildings with appropriate heat and solar protection and careful management of internal loads may reduce their cooling load down to 5 kWh/m^2/year, while buildings of low quality environmental design may present loads up to 450 kWh/m^2/year (Santamouris and Daskalaki, 1998).

Evaporative Cooling Techniques for Low Energy Consumption in Buildings

Evaporative cooling is a passive cooling technique in which outdoor air is cooled by evaporating water before it is introduced in the building whose physical principle lies in the fact that the heat of air is used to evaporate water, thus cooling the air, which in turn cools the living space in the building. It is a low energy passive system. There are basically two methods of evaporative cooling: direct and indirect evaporative cooling. The most commonly used evaporative cooling system in north India is the desert cooler consisting of water, evaporative pads, a fan and a pump. It is a hybrid type of direct evaporative cooling system (Sodha et al, 1986). In direct evaporative systems, the main disadvantage is the increased moisture content of the ventilation air supplied to the indoor spaces. High evaporation may result in discomfort due to high humidity. However, passive evaporative cooling can also be indirect, the roof can be cooled with a pond, wetted pads or spray, and the ceiling transformed into a cooling element that cools the space below by convection and radiation without raising the indoor humidity Givoni, 1994). There are many different methods to reduce the cooling load, but Passive Downdraught Evaporative Cooling (PDEC) and Roof Surface Evaporative Cooling (RSEC) and Direct Evaporative Cooling (Desert Coolers) are three most sustainable and viable methods. Since air conditioning is recognized as a significant factor in global warming and climate change, these three evaporative cooling techniques proves to be both technically and economically viable alternative, especially in hot-dry or composite climate as in India and where the cooling requirement is around 6-7 months in a year.

Direct Evaporative Cooling Using Drip Type Cooling

In northern India, desert coolers are very popular, since its capital and running cost is much lower compared to the refrigeration type of air conditioners and they can cool large volumes of outside air through evaporation of water. This air is delivered to the indoors where it absorbs heat from walls, ceilings, furnishings and the occupants. The warm air is finally discharged to the outdoors. Fresh outside air should be used rather than employing recirculation because, in the latter case, the wet bulb temperature continues to increase, resulting in unsatisfactory conditions. The cooler consists of a wetting pad, water circulating pump, a fan, and a cabinet to hold these components. The water pump lifts the sump water up to a distributing system, from which it runs down through the pads and back into the sump. The wetting pad–usually made of aspen wood fibres–is fixed to the

three sides of the coolers' walls in such a way that only air enters through the pads. A propeller-type fan or a centrifugal blower is used above the base of the cooler. The choice of the evaporating pad is a critical factor in determining the performance.

The coolers are usually designed for a face velocity of 1 to 1.5 m/s with a pressure drop of about 30 N/m2. In addition to providing cooling of the incoming air, the pads also act as air filters preventing the entry of particles having a size greater than 10 micrometers. The pads are chemically treated to prevent the growth of bacteria, fungi and other micro-organisms (Nayak and Prajapati, 2006).

Passive Downdraught Evaporative Cooling

The Passive Downdraught Evaporative Cooling (PDEC) consists of single or multiple towers equipped with a water vapour supply placed on the top. This innovation consists in the replacement of the wetted pads with rows of atomisers (nozzles, which produce an artificial fog by injecting water at high-pressure trough minute orifices). During the constant injection of water, droplets descend through the tower and conditions close to saturation along its length.

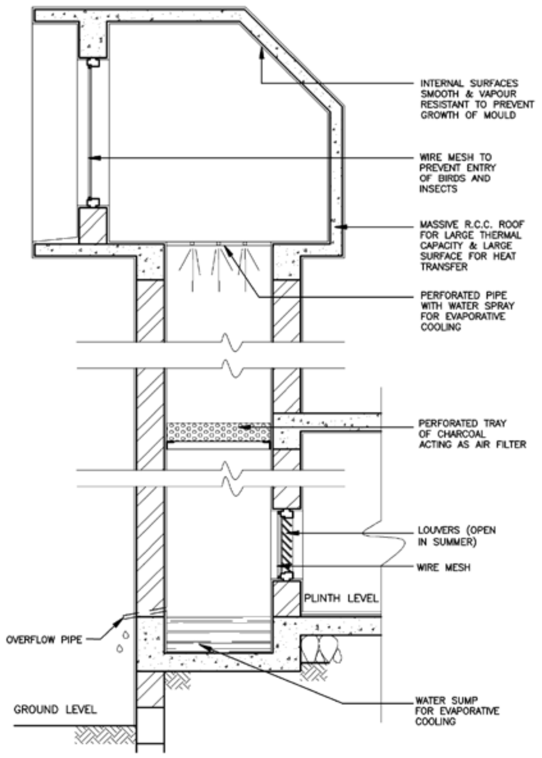

FIG. 1 DETAIL OF PASSIVE DOWNDRAUGHT EVAPORATIVE COOLING

Cool air descends the tower and exits at its base where it is delivered to the adjacent spaces as shown in Fig. 1. The concept is based on the relatively large amount of energy required to convert water from its liquid to gaseous form within a local thermal imbalance with subsequence differences in air density. This leads to the movement of air from a zone of high pressure, where air is hot and less dense (top of the tower) to a zone of lower pressure, where air is colder and denser (bottom of the tower). The situation of the micronisers in a tower gives rise to a naturally downdraught effect. These towers are often described as reverse chimneys. While the column of warm air rises in a chimney, in this case the column of cool air falls. The air flow rate depends on the efficiency of the evaporative cooling device, tower height and cross section, and resistance to air flow in the cooling device, tower into which it discharges (Thompson, Chalfoun and Yoklic, 1994).

Performance Analysis of PDEC System

In a research project funded by European Commission, Mario Cucinella Architects did an assessment of potential application of PDEC in Southern Europe. Table 1 summarizes the stock areas and potential energy savings of four European countries and shows that energy savings could be around 1.5% and 2.5% of the national electricity consumption (ALTENER, 2012).

Limitations of PDEC System

The hardness of water is a significant factor, therefore water quality has to be good otherwise nozzles will block. High pressures (>40 Bar) are required to minimize water droplet size and maximize evaporation, which implies more expensive pumps and plumbing. The risk of microbiological contamination of the water supply to the misting nozzles must also be minimized. This can be addressed by a combination of design measures (including the use of UV filters in the supply line to the micronizers), regular maintenance, and testing, but it would clearly be better if this was not an issue. In many parts of the world, the potential disadvantages of using micronizers (risks of microbiological contamination, blockage of micronizers, high-pressure stainless-steel plumbing fittings etc.), are a powerful disincentive.

'Low-Tech' solutions may be more appropriate in locations where water quality is poor, or where high-pressure plumbing is unfamiliar. The practical integration of such systems within the building envelope is fundamental to the feasibility of this approach. If simpler techniques currently under investigation do prove technically and financially viable, the market potential could be significant.

TABLE 1 POTENTIAL ENERGY SAVINGS THROUGH PDEC

Country	Commercial buildings area (millions m²)	National electricity consumption (millions KWh)	PDEC potential energy savings (millions KWh)	Energy saving as % of national electricity consumption	Reduction in CO2 emissions tonnes pa	Potential value of energy saving pa (million euro)
Greece	39	46,099	1,124	2.44%	766,596	85.4
Spain	116	201,159	3,341	1.66%	1,472,654	257.9
Italy	161	283,737	4,637	1.63%	2,809,643	490.4
Portugal	25	41,146	720	1.75%	391,414	59.0

Roof Surface Evaporative Cooling (RSEC)

In a tropical country like India, the solar radiation incident on roofs is very high in summer, leading to overheating of rooms below them. Roof surfaces can be effectively and inexpensively cooled by spraying water over suitable water-retentive materials (e.g., gunny bags) spread over the roof surface. As the water evaporates, it draws most of the required latent heat from the surface, which acts as a radiative cooling panel for the space, thus lowering its temperature and reducing heat gain. The indoor temperature gets lowered without elevating the humidity level. The solar radiation falling on the water film is utilized in water evaporation and thus being prevented from entering the room below. Besides, evaporation also cools the air above the roof. The cool air slides down and enters the living space through infiltration and ventilation, providing additional cooling (Jain, 2006).

Performance Analysis of RSEC Technique

The effectiveness of Roof Surface Evaporative Cooling (RSEC) technique depends on:

- ambient air temperature and humidity
- intensity of solar radiation
- wetness of the roof surface
- roof type

Kumar and Purohit investigated the performance of RSEC for various roof types under different climatic conditions (Kumar and Purohit, 2005). The basis of comparison for unconditioned buildings is the discomfort degree hours (DDH), defined as:

$$DDH = \sum_{month} \sum_{day} (T_R - T_C)^{+}$$

where T_R and T_C refer to the indoor air and set point temperatures respectively; the + superscript means that only positive values are to be considered.

Limitations of RSEC Technique

To install a roof surface evaporative cooling system, the following points need to be taken note of:

1. Suitable waterproofing treatment of the roof should be done.
2. The roof must be covered with water absorptive and retentive materials such as gunny bags, brick ballast, sintered fly-ash, coconut husk or coir matting. On account of their porosity, these materials when wet, behave like a free water surface for evaporation. The durability of such materials is rather good, but they have to be treated for fire safety.
3. During the peak period of summer, the quantity of water needed is approximately 10 kg/ day/ m2 of roof area.

The roof must be kept wet throughout the day using a water sprayer that can be manually operated or controlled by an automatic moisture-sensing device. The sprayer usually works at low water pressure which can be achieved either by a water head of the storage tank on the roof, or by a small water pump.

Conclusions

With climate change, energy efficient systems are required. Evaporative Cooling is a passive cooling technique which cools the building effectively and hence affecting building energy performance. Since the process is a bit cumbersome and initial cost of implementation is a bit more, therefore these techniques have not gained popularity. But considering the payback period, the results of the research have demonstrated that PDEC, RSEC and Direct Evaporative cooling are technically and economically viable. Incorporation of these evaporative cooling techniques would certainly reduce our dependency on artificial means for thermal comfort and minimize the environmental damage due to excessive consumption of energy and other natural resources and further will evolve a building form, climate responsive, more energy efficient, sustainable and environmental friendly buildings of tomorrow.

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Mohammad Arif Kamal was born in 1976 in Kanpur, India. He did his B.Arch. from Aligarh Muslim University, Aligarh, India in the year 2000 and completed his M. Arch. and Ph.D. from Indian Instittute of Technology, Roorkee, India in 2002 and 2007 respectively where he was awarded a government fellowship. Dr. Kamal's major field of study is environmental design and traditional architecture.

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